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Energy-water nexus in urban industrial system

Yi Lu[a], Bin Chen[a]*

[a]*State Key Joint Laboratory of Environmental Simulation and Pollution Control, School of Envrionment, Beijing Normal University, Beijing 100875, P.R. China*

Abstract

Energy and water are coupled in urban industrial systems in terms of energy-water nexus, playing key roles to sustain a city. This work proposed an environmental input-output analysis based methodological model to depict the nexus and reflect its dualistic impacts on the nature, which was applied into Beijing's case. Results show the agriculture and manufacturing sectors had the higher nexus intensities, playing as major energy consumers with higher embodied water consumption via the urban industrial chain. We hope this work would help to explore the energy-water nexus for urban system management.

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Keyworks: Energy-water nexus; Urban industrial system; Environmental input-output analysis; Water footprint; Resource Management

Nomenclature

Abbreviation

IOA	Input-output analysis
EIOA	Environmental input-output analysis

Symbols

* Corresponding author. Tel.: +0-000-000-0000 ; fax: +0-000-000-0000 .
E-mail address: author@institute.xxx .

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A	Technological coefficients
$Coef_e$	Carbon footprint coefficient
$Coef_w$	Water footprint coefficient
I	Identity matrix
F_e	Energy-induced carbon footprint
F_w	Water footprint
n	Total industrial sectors
X	Intermediated demand
x	Total demand
y	Final demand
Subscript	
i	i-th sector
j	j-th sector

1. Introduction

The energy-water nexus shows the interwoven energy and water in terms of resource use [1]. In this view, energy system directly consumes water in electricity generation and also indirectly uses embodied water along the industrial chain. Meanwhile, water system also needs energy to provide freshwater and dispose sewage [2].

The long existed interlink has called for increasing focuses due to the facts that demands for energy and water keep growing, but energy-induced carbon emissions and water scarcity are strictly controlled responding to climate change. Consequently, studies evaluated the energy intensity in water systems or the water intensity in energy systems to provide the quantitative basis in depicting the nexus [2-6]. Furthermore, researchers also investigated the amelioration potentials for regional resource management and infrastructure mainly in terms of alternative technologies and policy scenarios [1, 7-12].

City is a high density area for energy and water use [13], facing the increasingly strained conflicts between supply capacities and final demands of these interlinked resources. Therefore, in order to reflect the dualistic impacts on the nature, it is significant to unveil the mechanism, quantify and qualify the properties and improving potentials of energy-water nexus in urban systems, all of which have been preliminarily discussed [13-17]. However, we can find more room to investigate on this issue.

This work proposed a conceptual model to briefly depict the energy-water nexus in urban industrial system, and introduced the environmental input-output analysis to analyze the properties of the nexus. The methodological framework was also applied into Beijing's case. We hope this work can help to explore the mechanism and properties of energy-water nexus for urban system management.

2. Conceptual Model

In order to depict the mechanism of energy-water nexus in urban industrial system, a conceptual model with direct and embodied energy and water flows was shown in Fig. 1.

Diverse interlinked energy and water flows can be investigated between three key urban industries. The first industry (agriculture, forestry, livestock, fishery, etc.,) is the direct extractor and user of natural water mainly in terms of irrigation, livestock husbandry and aquaculture. Energy is also important to support the irrigation, pumping, crops storage, greenhouse and other devices, and thus to sustain the agricultural production. Second industry is the producer and consumer of energy and water. For instance, the sector of production and supply of energy and water extracts and converts raw materials (e.g. coal, oil, natural gas, natural water, etc.) to the power, heat, gas and freshwater, which are then transmitted and distributed to the end users in urban areas. These processed energy and water are partly used by the industrial sectors as mining, manufacturing and transportation, and also by the residential and public service sectors in the third industry.

Energy and water flows not only integrate urban industries together, also couple the urban energy and water systems in terms of the energy-water nexus.

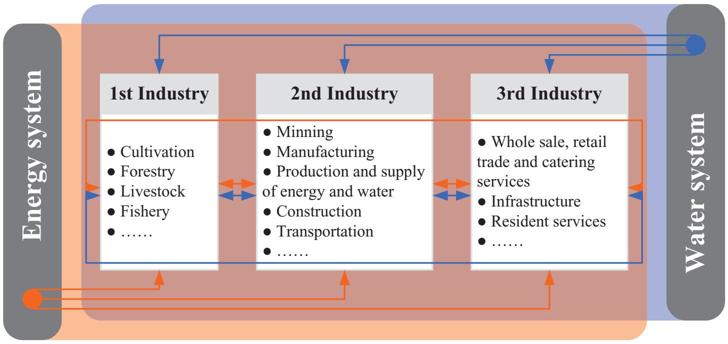

Fig. 1. Energy-water nexus in the urban industrial system.

3. Methodology

3.1. Input-Output Analysis (IOA)

IOA was developed by Leontief [18] to analyze industrial sectors' interdependence. The sectoral transactions consist of intermediate and final demand as follows,

$$x_i = \sum_{i=1}^{n} X_{ij} + y_i \tag{1}$$

where y is the final demand vector for all industrial sectors; X_{ij} is intermediated demand of sector j from sector i ($i, j = 1, \ldots, n$); x_i is the total demand from sector i.

The matrix of technological or direct requirement coefficients A relates the intermediated demand X_{ij} and the j-th sector's output x_j:

$$X_{ij} = a_{ij} \cdot x_j \tag{2}$$

A change in final demand y creates system-wide economic effects via the multiplier matrix or Leontief inverse matrix:

$$x = (I - A)^{-1} y \tag{3}$$

where I is the n-th order identity matrix; $(I\text{-}A)^{-1}$ is the Leontief inverse matrix indicating the total production of each industrial sector required to meet the final demand y in an economy [19].

3.2. Environmental Input-Output Analysis (EIOA)

EIOA is a popular tool for assessing resource or pollution associated with producing final demand along regional, national or global supply chains [19-21].

In this work, not only the direct use of energy and water in urban industrial system is investigated, the indirect use embodied in the raw materials, devices and intermediate products along the urban industrial chain [22-24] should be also considered. EIOA is feasible to quantify both direct and indirect use of energy and water by estimating the energy-induced carbon emissions and water footprints in all urban industrial sectors, which are expressed as

$$F_e = Coef_e(I - A)^{-1}y \tag{4}$$

$$F_w = Coef_w(I - A)^{-1}y \tag{5}$$

where F_e and F_w are vectors of energy-induced carbon and water footprints in urban industrial systems; $Coef_e$ and $Coef_w$ are the diagonalized footprint coefficients (i.e. carbon emissions and water withdrawals per unit of economic output) of all sectors [25, 26].

4. Results

We chose Beijing as the case area, whose primary data was derived from the latest 42 sectors input-output table of Beijing in 2010. All of the urban industrial sectors were aggregated into 5 categories due to the function each sector undertook.

Table 1 showed the results of the energy-induced carbon emission, water footprints and the nexus intensity (i.e. water withdrawals per unit of energy-induced emissions) of Beijing. We found all aggregated industrial sectors in Beijing were carbon emitters at expense of higher embodied water consumption via the urban industrial chain. The higher nexus intensity (65.78 m3/t) of agriculture unveiled it was the significant user of water with the least emissions. Manufacturing was also nexus-intensive (54.35 m3/t) with the highest carbon emissions and water withdrawals in the second industry, mainly due to the energy production and chemicals manufacturing, which should be optimized.

Table 1. The nexus intensity of Beijing in 2010.

Industrial Sector	Carbon emissions (million t)	Water withdrawals (million m^3)	Nexus intensity (m^3/t)
Agriculture	0.59	38.84	65.78
Manufacturing	66.01	3588.16	54.35
Construction	1.12	1.90	1.70
Transportation	16.38	17.08	1.04
Service	25.07	101.54	4.05

5. Conclusions

Energy-water nexus couples the energy and water system in urban industrial system. This work proposed a theoretical framework to depict and measure the energy-water nexus in urban industrial system based on environmental input-output analysis. Beijing was chosen as the case area, whose agricultural and manufacturing sectors were the major energy consumers with higher embodied water footprint. This work may help to unveil more about the energy-water nexus in urban industrial system for urban management.

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Biography

Bin Chen is a professor of energy science at Beijing Normal University. Dr. Chen has published over 200 peer-reviewed papers in prestigious international journals. He is also serving as subject editor of Applied Energy and editorial board member of more than ten journals.